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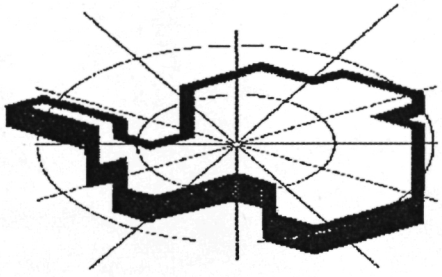
BELGIAN SCIENTIFIC RESEARCH PROGRAMME ON THE ANTARCTIC

1992-1996 RESEARCH RESULTS SUMMARY



Brussels - May 1997

CONTENTS

1 INTRODUCTION

This volume presents an overview of the results of the research projects funded under the *Third Phase* of the *Belgian Scientific Research Programme on the Antarctic (1992-1996)*.

The programme, which was initiated by the Belgian Government in 1985, is funded, managed and co-ordinated by the *Federal Office for Scientific, Technical and Cultural Affairs (OSTC)*. The money allocated to the Third Phase was 160,000,000 BEF. Research-work was implemented by means of 3-years projects undertaken by university- or federal scientific institute-based scientists.

All research costs (personnel, equipment, travel, working and overheads) were financed by OSTC.

Such research effort aimed at contributing to the development of the knowledge required for a science-based conservation and management of the Antarctic environment and to the assessment of the mechanisms through which the Antarctic and the global climate interact. Emphasis was given on a multi-disciplinary approach of the dynamics of the global functioning of Antarctic main natural systems and of their evolution and interactions. The programme comprises seven research lines under three priority areas. They are:

- ECODYNAMICS OF THE SOUTHERN OCEAN AND INTERACTIONS WITH THE CLIMATE:
  - Biogeochemical fluxes and cycles in the main trophic compartments
  - Modelling the global dynamics of ecosystems
  - Assessment of the role of "new production" in the burial of atmospheric CO_2 by the Southern Ocean

- EVOLUTION AND PROTECTION OF MARINE ECOSYSTEMS:
  - Application of predictive ecological models to simulate ecosystem responses to man-made climatic disturbances
  - Study of hydrocarbons spills dispersion

- ROLE OF THE ANTARCTIC IN GLOBAL CHANGES:
  - Ocean-Cryosphere-Atmosphere interactions.
  - Sedimentary palaeoenvironment.

At present, Belgium's commitment in scientific research on the Antarctic is covered by the *Fourth Phase of the Programme (1997-2000)*. The overall budget of this new phase amounts to 236,000,000 BEF.

Details on the Programme as well as on ongoing research projects are available at *http://www.belspo.be/antar*.

2 RESEARCH WORK

PROJECT A3/03/001 - Dr F. DEHAIRS and Dr L. GOEYENS (VUB)

SPATIAL AND SEASONAL VARIABILITY OF BIOGENIC ELEMENTAL TRANSPORT IN THE SOUTHERN OCEAN

This study focused on the investigation of two intensely related fluxes in the Southern Ocean:

- the nutrient uptake regime, with main emphasis on the uptake of nitrogen sources
- the type and intensity of export production towards the deeper layers and the sediments.

The separation in Southern Ocean provinces of silicate excess at nitrate exhaustion and of nitrate excess at silicate exhaustion, as suggested by Kamykowski and Zentara (1985, 1989), was supported by our investigations of the silicate to nitrate uptake ratios. Oligotrophic Antarctic waters mainly exhibit proportionally higher silicate removal what induces a potential for nitrate excess. The nitrogen uptake regime of such areas is characterised by low absolute as well as specific nitrate uptake rates throughout. Maximal values did not exceed 0.15 μM d^{-1} and 0.005 h^{-1}, respectively. Corresponding f-ratios ranged from 0.39 to 0.86.

This scenario contrasts strikingly to the more fertile ice edge areas. They showed a drastic but short vernal increase in nitrate uptake. Absolute uptake rates reached a maximum value of 2.18 μM d^{-1} whereas the maximal specific uptake rate was 0.063 h^{-1}. This peak nitrate utilisation during early spring led to the observed potential for silicate excess. With increasing seasonal maturity the nitrate uptake became inhibited by the presence of enhanced ammonium availability (up to 8 % of the inorganic nitrogen pool), however, and after a short period of intensive nitrate consumption the uptake rates drop to very low levels, comparable to the ones observed in the area of nitrate excess at silicate exhaustion.

The nitrogen uptake by phytoplankton was also studied in relation to the biomass and structure of the community in the Atlantic and Indian sectors of the Southern Ocean. Two distinct scenarios for the seasonal evolution of the uptake regime and the phytoplankton community structure were observed:

- ✓ In the Marginal Ice Zone of the Scotia-Weddell Confluence area, the transition from a predominantly nitrate based system to a predominantly ammonium based one was paralleled by the disappearance of diatom dominance and the concomitant development of a dense flagellate dominated phytoplankton community.
- ✓ In the Coastal and Continental Shelf Zone and Open Oceanic Zone of the Indian sector, the shift in the nitrogen uptake regime occurred without significant change in the phytoplankton community structure. Diatoms dominated the assemblage throughout and about 80 % of the phytoplankton biomass was in the 10 μm size fraction. Unlike the first scenario, diatoms predominantly consumed ammonium. Thus, in areas of persistent water column stability and less selective grazing pressure, a shift in the uptake regime can occur without changes in the community structure. The dominance of diatoms under regenerated production provides, furthermore, physiological supports for the observed potential for nitrate excess in oligotrophic Antarctic waters.

Export flux as reflected by mesopelagic stocks of particulate Ba-barite, was found to be strongly dependent on the type of production. In environments with predominant regenerated production, export production did not sustain significant Ba-barite accumulation. This appeared to be the characteristic situation for environments having shallow mixed layers as a result of melt water input, such as the N-W Weddell Sea and the Prydz Bay area. Although in these environments algal growth was high grazing pressure was also high, as witnessed by high subsurface ammonium.

Open ocean areas, on the contrary, had larger export fluxes despite their lower surface productivities and lower algal biomasses. The latter properties resulted from deeper mixed surface layers and relatively reduced grazing pressures (poor ammonium build-up). The Polar Front region appeared to be an intermediate system. Furthermore, an empirical relationship was observed between mesopelagic Ba-barite stocks and oxygen consumption. This enabled us to write a transfer function relating mesopelagic particulate Ba concentrations and the fraction of exported carbon respired in the mesopelagic water column (Dehairs et al., 1996). This function was applied to the whole of our Southern Ocean data set. Export production obtained from mesopelagic Ba accumulation was subsequently compared to sediment trap Ba fluxes.

Comparison of export production rates calculated from mesopelagic Ba stocks with rates calculated from sediment trap Ba fluxes (the latter from Nürnberg et al. 1995) was possible for the PFZ of the Atlantic sector. Both approaches produced similar results. For the Indian sector (60° E) export production estimated from mesopelagic Ba ranges between 20 mg $C.m^{-2}.d^{-1}$ for the Prydz Bay shelf region to 80 mg $C.m^{-2}.d^{-1}$ just south of the Polar Front, representing respectively between 1 and 41 % of primary production.

References:

Dehairs F., Shopova D., Ober S., Veth C. and Goeyens L. (1997): Particulate barium stocks and oxygen consumption in the Southern Ocean mesoplegagic water column during spring and early summer: relationship with export production, Deep-Sea Res. Part II, 497-516.

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Kamykowski D., and Zentara S.J. (1985): Nitrate and silicic acid in the world ocean: patterns and processes. Mar. Ecol. Prog. Ser., 26: 47-59.

Nürnberg C.C. (1995): Bariumfluss und Sedimentation im südlichen Südatlantik - Hinweise auf Produktivitätsänderungen im Quartär, Geomar Report 38, 105 pp.

PROJECT A3/02/001 - Dr M. VINCX (RUG)

ROLE OF THE MEIOBENTHOS IN ANTARCTIC ECOSYSTEMS

The relative importance of the meiofauna (size in the range of 38-1000 μm) in the Antarctic benthic community has been assessed by a combined field ecology and experimental approach. This was done in two contrasting conditions, e.g. the deep sea and low subtidal, where as to the depth of the water column the benthic characteristics were, respectively, indirectly or directly related to primary production.

Deep-sea samples were collected at Kapp Norvegia and Halley Bay (Weddell Sea) during the EPOS-leg 3 campaign (austral summer 1989) on board the *R/V Polarstern* at depths between 200 and 2000 m. Samples for the ecological experimental approach of the meiofauna in the low subtidal were taken at Signy Island at a water depth of 10 m, opposite the British Signy base. This was done fortnightly during 18 months in 1991/92 and during the summer of 1994. A set of environmental variables (oxygen, pore-water nutrients, particulate and dissolved organic matter, sediment texture, chloroplastic pigments, bacteria and diatoms) were concurrently monitored.

Despite the apparent harshness of the Antarctic environment the meiofauna thrived with high productive stocks, sometimes much higher than their temperate and tropical relatives. Numbers and biomass were more or less seasonal and interannual varying (in the case of the subtidal meiofauna). Correlation with environmental factors revealed that depth, sediment texture, oxygen availability, variations in organic matter flux to the sediment surface, and hence food, governed the meiobenthic distribution patterns. Towards this, minimum nematode production constituted 2 % of primary production in the pelagial and 11 % of the downward flux of organic matter to the seabed.

The energetic position of the meiofauna and their share in the remineralization processes and hence, reintroduction of regenerated nutrients and organic carbon through the sediment/water interface back into the water column, was inferred from flux measurements of nutrients, oxygen and organic matter. Grazing experiments with radio-labelled isotopes, used to quantify the carbon transfer between microbiota and their meiobenthic grazers (mainly epistratum and non-selective deposit-feeders), showed a clearance rate of 5.1x 10^{-4}xh^{-1}. Yet, about 10 % of the annual benthic carbon production was grazed down by nematodes. Nutrient and oxygen fluxes were measured from concentration changes in incubation chambers and vertical profiles in the sediment core. The results evidenced an efflux of ammonia and phosphate to the water column and an uptake of nitrate and silicate by the sediments.

Respiratory activity was measured by a combined method of individual nematode and bulk sediment oxygen uptake. With an individual respiration of 0.89-2.77 nl O_2xind^{-1}xh^{-1} (Q10 = 2) the nematode community contributed to a substantial proportion of benthic remineralization processes (13-42 % of the total benthic carbon demand was due to nematode respiration).

Secondary production by the nematode community at Factory Cove was among the highest in the world (P varying between 2.2 and 72.4 gCm^{-2} x y^{-1}), and accounted for 9.4 % of total benthic production, 4.1 % of phytoplankton production and 11.9 % of microphyto-benthic production.

From the flux measurements and production estimates it was suggested that, by using the substantial episodic food supply (both from water column and in situ production) very efficiently, the meiofauna might play a potentially important role in the energy transfer through the differing benthic components and from the sediment back into the water column.

PROJECT A3/12/001 - Dr J.-H. HECQ (ULg)

CONTROL OF THE ANTARCTIC PELAGIC ECOSYSTEM BY HIGHER TROPHIC LEVELS IN RELATION WITH ENVIRONMENTAL CHANGES

The productivity and biodiversity of the Ross Sea pelagic ecosystem were studied in relation with its specific environmental features. The variability which results both in spatial individualization of local sub-ecosystems and seasonal changes of those sub-ecosystems have been identified in collaboration with the Italian PNRA Programme.

Following the main objective which was to analyze and link physical and biological processes at different scales which govern the Southern Ocean global ecosystems and to determine the potential resilience to climatic and anthropogenic changes, we have developed and implemented a coupled physical/biological model able to simulate these multi-parametric constraints.

Data obtained during the Ross Sea cruises have confirmed that the most important factors regulating the Antarctic pelagic food chain are physical processes operating within the circumpolar marginal ice zone during the ice melting period. As a typical characteristic of the Ross Sea, the ice free surface of the polynia is propagating from the South to the North, with an increase of the water surface exposed to the sunlight. The diversity of biota assemblages in Ross Sea area seems attributable to a specific control by local constraints rather than to the presence of specific sub-ecosystem:

- the ice edge melting is not simultaneous for the whole region,
- the central and southern part opening sooner than the lateral part;
- the areas of depth shallower than 500 m seems to be inaccessible to krill which is strongly influencing the utilisation of primary production; and,
- the ice algae content is more important in the western part.

The concentration of phytoplankton pigments and their grazing-degradation products have been specifically determined by means of HPLC in the water column, in the ice, suspended sediments, zooplankton and krill digestive systems and in faecal pellets. Pigments values were used as algae tracers of fluxes across the food chain in the upper layers of the water column and as data for parameterizing, calibrating and validating ecological models.

The main part of the Southern Ross Sea was dominated by Phaeocystis pigments (hexanoyl-oxy-fucoxanthin and chlorophyll C3). The diatoms pigment (fucoxanthin) dominated in high concentrations overall in coastal areas, in the ice and in the water column and in the central Ross Sea, at the northern limit of the polynia. In that area, the phaeophorbid high concentration assumes high krill grazing which reduce diatoms bloom. The results have completed the hypothesis of distribution of ice algae pigments in relation with ice retreat and emphasised the temporal succession of various algae groups like cryptophytes and prasinophytes and the control of primary production exportation by grazing.

Data acquired in the Ross Sea have been used to developed a coupled physical/biological one-dimensional model of the upper water column model with a k-1 turbulent closure. The model is used to simulate how the small scale physical processes of vertical stabilization of the water column within the Ross Sea marginal ice zones during ice melting period influence the physical and biological structure of upper layers and stimulate primary

production, select the type of phyto- and zooplankton communities, control the vertical distribution of zooplankton and metabolic products (faecal pellets, NH_4 ...) and finally control the upper trophic levels.

At the upper edge of the Southern Ocean ecosystem scale, changes correlated with whaling are relevant and the krill increase due to their exploitation seems to induce, allowing for faster growth, higher pregnancy rates and earlier sexual maturity. The hypothesis of food-limited by the whale stocks before whaling period, and the increase of the krill availability for others consumers: birds, seals and remaining whales related to industrial whale catching have been tested by a numerical model for the upper trophic levels of the Antarctic food chain.

Simulation without whaling activities emphasizes equilibrium in the system.

Simulation of the system with real fisheries statistics until 1990 and assuming constant whaling equal to actual levels after 1990 or no whaling activities after 1990 determined the influence of whaling on resilience of the whale stocks for the future.
The model validates the hypothesis of krill-limitation by the whale stocks before whaling period and also the control function of whaling on all upper trophic levels of the Antarctic food chain.

PROJECT A3/11/001 - Dr Ch. LANCELOT (ULB)

DYNAMICS OF THE PLANKTONIC MICROBIAL FOOD-WEB OF THE SOUTHERN OCEAN IN RESPONSE TO ENVIRONMENTAL CHANGES

Physical, chemical and biological conditions governing phytoplankton bloom development and food chain structure in the Southern Ocean were investigated, based on field observations and mathematical modelling. Particular attention was paid to sea-ice dynamics and wind stress in triggering phytoplankton bloom induction, and to iron and krill as vector of food chain structure and related surface carbon retention vs exportation. Research focused on conditions determining the development of diatoms- vs nanoflagellates-dominated phytoplankton communities as well as on the dynamics of the microbial food web.

Sampled sites were crossing areas with contrasting meteorological conditions and sea-ice dynamics, dissolved iron availability and krill inhabitance, namely:

- the EPOS site in the iron-rich marginal ice zone of the northwestern Weddell Sea, crossed by krill swarms and experiencing in spring-summer 1988 extremely favourable meteorological conditions (average wind: 7m/s);
- the ANTX/6 site crossing at 6° W the iron-rich Polar Frontal Jet and the sea-ice-associated iron-deficient Antarctic Circumpolar Current while submitted in early spring 1992 to severe meteorological conditions (average wind: 11m/s); and,
- the iron-sufficient ANTARES 2 site in the Indian sector of the Southern Ocean and experiencing in late summer 1994 auspicious meteorological conditions.

Biomass of autotrophic (diatoms and nanoflagellates) and heterotrophic (bacteria, bactivorous and herbivorous protozoa) microorganisms were spatio-temporally measured and their mutual interactions were assessed. Process-oriented studies were conducted for determining the physiological characteristics of diatoms and nanoflagellates growth and the feeding functional properties of the protozoan community.

It is shown that diatoms and nanoflagellates growth differs by the only iron biochemistry and affinity for iron concentration, photosynthetic properties being identical for both phytoplankton groups. The protozoan community can be regarded as composed of two groups characterized by their own diet and feeding characteristics: the strictly bactivorous heterotrophic nanoflagellates and the protistovorous protozoa feeding on almost exclusively the auto- and heterotrophic flagellates. Furthermore ingestion rates of these two communities can be described by a specific food saturation function above a threshold food concentration below which feeding does not occur. Based on these results, the numerical code of the 1D mechanistic SWAMCO model, describing carbon, nitrogen and iron cycling through the microbial food chain closed by copepod grazing pressure was established. The SWAMCO model was calibrated and validated on the ANTX/6 site.

Observational ecosystem analysis and mathematical simulations with the 1D coupled physical-biological SWAMCO model forced by the chemical and meteorological conditions during the EPOS and ANTX/6 expeditions show the tight coupling between atmospheric forcing - most notable in frequency, duration and strength of storm events - and phytoplankton blooms occurrence.

It was demonstrated that:

- ✓ the sustained windy meteorological conditions prevailing during the ANTX/6 expedition was the main factor preventing blooms from developing at the receding ice-edge; and,

- ✓ under events of favourable meteorological conditions for phytoplankton bloom initiation, the structure of the developing phytoplankton community is determined by iron availability with nanoflagellates outcompeting diatoms at iron sub-nanomolar concentration.

Hence it can be safely concluded that the general HNLC (High Nutrient Low Chlorophyll) conditions of the Southern Ocean are resulting from the successful development of grazer-controlled nanophytoplanktonic communities in a low-iron environment. Superimposing this active microbial food web, episodic blooms of diatoms are well developing in iron-enriched areas experiencing favourable meteorological conditions like near-shore neritic areas supplied with iron from shelf sediments, the rapidly eastward flowing Polar Frontal Jet retaining a significant signal of iron from shelf source and to a less extent some sea-ice covered areas having cumulated minor annual aerosol inputs. When optimal light conditions are maintained diatom growth is however limited by iron availability and/or krill grazing pressure and the phytoplankton community structure shifts towards a nanoflagellates dominance.

PROJECT A3/58/001 - Dr G. PICHOT (MUMM)

OIL SPILL MODELLING FOR THE ANTARCTIC SEAS (OSMAS)

A model of oil behaviour in ice-infested waters has been developed, which describes the interactions between oil and ice coupled with a sea ice formation model. The main features of oil spreading and dynamics in an ice pack are taken into account in the model which has been tested in three different situations: at short term in cold waters and in the presence of ice, and at long term.

On the basis of existing literature and observations, interactions between ice and oil have been identified and introduced in a sea ice formation model to study the possible fate of oil pollution in the Weddell Sea. The experiment shows that the mean drift of oil follows the Weddell Gyre, which takes the remaining contamination toward the circumpolar current. It appears clearly that the presence of ice pack completely modifies the evolution of an oil slick which acts as a moving boundary, controlling the spreading and the drift of an oil slick.

One of the key results of the long term scenario is to show that almost 20% of the initially released oil cause later and further away a second pollution event. Since the evolution of the oil slick strongly depends on the way that oil and ice interact and since each accident has thus its own features, it is evident that, in other circumstances, a greater percentage or even all the oil could be blocked under ice provoking this kind of delayed pollution, which cannot be considered any more as "accidental".

If one has to admit that logistical difficulties inherent to the Antarctic area hamper appropriate reactions in the very beginning of an accident, that is no more the case when one has in advance clear information on the time of an oil spill, its position, and the involved quantities, which is the case for this second spill.

Without prejudice to complementary efforts concerning its validation, a major interest of the present model is to provide a tool able to deliver such information to authorities and intervention teams who would thus not be caught off their guard.

The results of such research-work were presented at the XXth Antarctic Treaty Consultative Meeting held in Utrecht from 29 April to 10 May 1996 (XX ATCM INFO paper 47). As an outcome the MUMM and the British Antarctic Survey implemented a joint study on the application of computer models to spill response. Such study is summarized hereafter.

PREPAREDNESS TO OIL SPILL POLLUTION: A CASE STUDY (IN COOPERATION WITH BAS)

In 1996, the British Antarctic Survey examined contingency planning for oil spill response in Antarctica, and evaluated the capacities of Antarctic research stations and ships to react to pollution incidents. As part of this study, the BAS studied the use of oil spill simulation models as management tools to help in spill response.

The BAS discovered that the only computer model designed specifically for examining the trajectory and fate of oil spills in Antarctica had been developed by the Management Unit of the Mathematical Model of the North Sea and Scheldt Estuary (MUMM, Brussels) as part of the Belgian Scientific Research Programme on the Antarctic. This model had been developed for oil spills occurring in the Weddell Sea.

The MUMM and BAS collaborated in running the model for different scenarios designed by BAS to investigate the possible consequences of a major fuel spill. Data were supplied by BAS and Environment Canada. The scenarios involved the release of 163,000 litres of marine gas oil (e.g. the loss of a resupply or scientific vessel) at different locations in the Weddell Sea. The results provided by MUMM to BAS consisted of oil slick trajectories, and forecasts of the weathering of the fuel and pack ice conditions.

The joint study showed how useful computer models could be in spill response operations. Further development of this kind of model will benefit from close collaboration between modellers and people with practical experience of working in the Antarctic and dealing with actual incidents.

PROJECT A3/11/002 - Prof. R. SOUCHEZ (ULB)

ISOTOPIC AND CHEMICAL COMPOSITION OF ANTARCTIC SHELF ICE: IMPLICATIONS ON GLOBAL CHANGES

In the context of global warming, the question of the stability of Antarctic ice shelves is critical for predicting any sea level rise. Small ice shelves are likely to react more rapidly than large ones to a change in atmospheric and oceanic temperatures.

The behaviour of ice shelves and floating ice tongues is dependent on their boundary conditions. At the ice-ocean interface, these boundary conditions can be appraised by studying:

- the properties of marine ice forming accretions at the base;
- the properties of the water column in front and under the ice shelves.

Two case studies were considered in this research-work, both in the Terra Nova Bay area, Victoria Land, of which conclusions are summarized hereunder.

In the first case, marine ice is formed near the grounding line here defined as the limit between grounded ice and floating ice, either if the glacier goes afloat or becomes again grounded. Two different types of marine ice have been found. Type 1 is bubble-and debris-free ice with properties which can be explained by intrusion of brackish water in open basal fissures. Closing of the fissures by progression of a freezing front from the sides is precluded and filling by frazil ice is favoured. Type 2 is made of thin clear ice and debris layers which are thought to have formed when a subglacial water-filled sediment enters into contact with sea water and is subjected to freezing under a double diffusion process. It is also stressed that, in a $\delta D/\delta^{18}O$ diagram, the alignment of marine ice samples on a mixing line does not, necessarily, imply a mixture of continental water and sea water in varying proportions.

In the second case, extensive frazil ice accumulation occurs under the ice shelf. Two main frazil ice types can be identified which have different crystallographic, isotopic and chemical characteristics indicating contrasted depositional environments.

Results from oceanic water sampling at various time periods clearly show the occurrence of oceanic circulation mode 3 as defined by Jacobs et al. (1992). In this mode, tidal pumping allows seasonally warm waters of the coastal currents to make contact with the base of the ice shelf , to produce melting and to form Ice Shelf Water (ISW) exiting at the front of the ice shelf. The wide occurrence of orbicular frazil ice accreted upstream at the bottom of the ice shelf is the result of circulation mode 1, i.e. deep thermohaline circulation. Banded frazil ice is generated closer to the ice shelf front by adiabatic supercooling or by a double-diffusion process at the limit between ISW-mode 1 and ISW-mode 3, thus partially impeding the net melting loss due to circulation mode 3.

Reference:

Jacobs S.S., Helmer H.H., Doake C.S.M., Jenkins A. and Frolich R.M. (1992): Melting of ice shelves and the mass balance of Antarctica. J. of Glaciol., 38 (130): 375-387.

PROJECT A3/10/001 - Prof. A. BERGER (UCL)

FORMATION OF THE TERRA NOVA BAY POLYNIA AND CLIMATIC IMPLICATIONS

A preliminary simulation of the Terra Nova Bay polynya was achieved by means of a coupled atmosphere-polynya model.

The three-dimensional Atmospheric Mesoscale Circulation Model (MAR) has been coupled to a wind-driven polynya model, generalized from that of Ou (1988), by including sea-ice dynamics and thermodynamics. The atmospheric model is a hydrostatic primitive equations model that has been validated previously by a simulation of the strong katabatic winds observed in this area. The polynya model includes a representation of the free drift of frazil ice and simple sea-ice dynamics and thermodynamics.

Two-dimensional and three-dimensional experiments have been performed under polar night conditions.

The atmospheric model sensitivity to the presence of a prescribed coastal polynya was analyzed by performing two-dimensional simulations. For sufficiently large areas of open water located in the coastal zone, a strong ice breeze is superimposed on the katabatic flow, causing subsidence of warm maritime air over the ice sheet and a subsequent intensification of the inversion and the katabatic wind. Nevertheless this has little impact on the polynya size predicted by the Pease (1987) model, since stronger katabatic winds reinforce the heat exchange between the polynya and the atmosphere. On the other hand the decay of katabatic winds over the ocean has an impact on the polynya size, owing to internal stresses in consolidated sea ice.

A simulation of the Terra Nova Bay polynya was also performed with the three-dimensional version of the model. The size of the simulated polynya is in qualitative agreement with the observations. As for the two-dimensional experiments, the katabatic flow is significantly reinforced over the ice-sheet slopes in the vicinity of the polynya (i.e. over Reeves Glacier). Observation and simulation of the katabatic wind in this area were in good agreement.

The simulated heat losses from the Terra Nova Bay polynya were shown to be larger by a factor 2 than in previous estimates, so that brine rejection into the ocean could also be more important than expected. Nevertheless processes like the consolidation of frazil ice into pancake ice are still poorly understood and not included in the model, leading to an overestimation of the simulated heat losses. Other missing processes, like frazil ice herding by wind waves, could have a strong impact on the polynya size. This stresses the need for having a better knowledge of the processes governing the frazil ice evolution in the Terra Nova Bay polynya, in order to develop new parameterizations. Because it provides a realistic atmospheric forcing, the atmospheric model used here could be an useful tool for developing such parameterization.

References:

Ou H.W. (1988): A time-dependent model of coastal polynia, J. Phys. Oceanogr., 18: 584-590.

Pease C.H. (1987): the size of wind-driven coastal polynias, J. Geophys. Res., 92: 7049-7059.

PROJECT A3/03/002 - Prof. H. DECLEIR (VUB)

DYNAMICS OF THE ANTARCTIC ICE CAP AND CLIMATE CHANGES

In this study we examined:

- the stability of the ice sheet in East Dronning Maud Land and Enderby Land where it is drained by a large fast-flowing continental ice stream (Shirase Glacier); and,
- the regional behaviour of the Antarctic ice sheet in East Dronning Maud Land in function of environmental change over a period of the last 200,000 years. Both tasks were accomplished by numerical modelling of the ice sheet system and by satellite remote sensing.

For this purpose we developed a flexible and multi-purpose flow line model allowing us to study the relevant glaciological processes in ice stream behaviour on the one hand and capable of linking, on sound physical principles, the observed climatic signal from ice core data with the geomorphological data as observed in the ice free areas, on the other hand. With respect to the observed glaciological parameters we also developed a method for deriving glacier variations from sequential satellite images by an automatic matching technique.

The analysis itself focused on the period of the last 200,000 years with special interest in the last glacial-Holocene transition and the present day dynamical situation:

- ✓ Since field evidence from Shirase Drainage Basin reports a rapid thinning of the ice sheet, model experiments were carried out to shed a light on the relevant physical processes responsible for ice stream behaviour. Indeed, from preliminary experiments (Pattyn and Decleir, 1995) it was found that the large thinning rate in Shirase Drainage Basin could not be explained as a response to the climate signal alone. Some other mechanism should account for this.

  By carrying out simulations with different basal boundary conditions, a thermally regulated cyclic behaviour, related to the hydraulic conditions at the bed (water pressure, basal melting and meltwater flow) could be observed, giving rise to a partial disintegration of the ice sheet (Pattyn, 1996). Yet, the ice loss was confined to the stream area and did not influence the inland ice sheet near the Polar Plateau. The high imbalance values (in accord with observations) could be explained by the small period in the cyclicity, hence a large ice discharge was not necessary. Whether this mechanism applies to Shirase Glacier awaits future field work to disentangle the basal properties of this fast-flowing outlet glacier.

- ✓ Recent glacio-geological and geomorphological field evidences in the neighbouring Sør Rondane Mountains point - as elsewhere in Antarctica - to a relative stable ice sheet cover during the last million years. This was confirmed by applying different model scenarios of the behaviour of Gjelbreen, an outlet glacier of this mountain range. Results of the 'best fit' scenario, i.e. the model outcome which is closest to the field evidence, showed that the present ice sheet in the Sør Rondane is close to its maximum position of the last glacial-interglacial period. This proves that the ice sheet is out of phase with the climatic signal and explains the small observed differences in glacier stand between the present and the maximum.

However, over the last 200,000 years the glacier variations amount to 100-200 m. Our modelling experiments clearly indicate that both the position on the glacier (coastal, mountain and inland ice sheet) and the timing of the response is essential to make a comparison with field observations elsewhere.

References:

Pattyn F. (in press): Numerical modelling of a fast flowing outlet glacier: experiments with different basal conditions. Ann. Glaciol., 23:

Pattyn F. and Decleir H. (1995): Numerical simulation of Shirase Glacier, East Queen Maud Land, Antarctica. Proc. NIPR Symp. Polar Meteorol. Glaciol., 9: 87-109.

PROJECT A3/02/002 - Dr M. DE BATIST (RUG)

BELGIAN CONTRIBUTION TO ANTOSTRAT PROJECT (BELANTOSTRAT)

The scientific objective of ANTOSTRAT - the "Antarctic Offshore Acoustic Stratigraphy" Project - is to extract Antarctica's Cenozoic glacial history from the sediments of its continental margins. The Belgian scientific contribution to ANTOSTRAT consisted of seismic-stratigraphic studies of three portions of the Antarctic continental margin.

The studied areas are situated along portions of the Antarctic continental margin that exhibit different characteristics, such as different glacial regimes and glacial evolution (West-Antarctica as opposed to East-Antarctica), different depositional processes and environments (semi-enclosed basins, quasi-starved distal glacial-marine environments, deep-sea fan and drift environments, etc.) or different preservation potential (subsiding shelf edge in Bransfield Basin as opposed to stable shelf edges in Weddell Sea or along the Amundsen-Bellingshausen margin).

1) *The Trinity Peninsula and South Shetland Islands margins of central Bransfield Basin:*

Swath bathymetry data acquired in central Bransfield Basin during the GEBRA-93 survey reveal new morphological features and trends that shed a light on the ongoing processes of back-arc basin formation and evolution. Basin compartmentalisation and progressive deepening towards the north-east via a series of bathymetrical steps suggests a progressive increase in basin maturity in that direction. The different shapes and sizes of large volcanic edifices dominating the basin-floor morphology can be interpreted in terms of successive evolutionary stages of incipient sea-floor spreading.

New high-resolution reflection seismic data indicate that the upper-slope deposits along the Trinity Peninsula margin contain resolvable records of at least three periods - since the Pliocene, beginning of the opening of Bransfield Basin - during which ice sheets advanced to the shelf edge for a significant amount of time. The record of glacial periods of lesser extent is probably not preserved in the upper-slope and shelf deposits as suggested by the strong erosional unconformities.
Magnitude of slope progradation varies along the Trinity Peninsula margin and appears to be related to local sources of sediment supply associated with separate glacial troughs. Ice-stream activity within these troughs appears to have varied through time. A thick stack of prograding units is preserved at the mouth of Orleans Trough. Off the mouth of the Antarctic Sound, most of the correlative section has been removed by canyon incision at the Gebra Valley.

Development of basin-floor strata appears to be temporally distinct from the development of the prograding upper-slope wedges, the toes of which downlap the basin floor strata. A drill hole (recently submitted ANTOSTRAT-ODP Proposal) through this basin-floor section would provide an excellent opportunity to constrain the age of the glacial cycles associated with the progradational wedges.

2) *The West-Antarctic continental margins of the Bellingshausen and Amundsen seas:*

A regionally-spaced reflection seismic data set has been acquired from the hitherto largely unexplored Bellingshausen and Amundsen Seas along the West Antarctic margin during the ANT XI/3 survey in 1994. These data show the large-scale stratigraphic architecture of the continental shelf, slope and rise, and contain a record of the long-term glacial history of the area. On all seismic profiles, the same variation of outer-shelf geometries is observed: (i) a lower unit of mainly aggradational sequences; (ii) a middle unit of strongly prograding sequences; and, (iii) an upper unit exhibiting both progradation and aggradation. The lower aggradational sequences are thought to represent conditions before the onset of the major glacial advance of a grounded ice sheet, whereas the overlying sequences probably record several extended periods of ice-sheet grounding on the shelf since the Middle Miocene.

A prominent erosional surface defines the base of a prograding wedge occupying the continental slope along the margin. It is tentatively correlated with the transition from aggrading to prograding sequences on the outer shelf, and may thus reflect an intensification of the bottom current regime in the lower parts of the palaeo-slope at response to the onset of glacial conditions on the continental shelf.

Sedimentation on the continental rise appears to have resulted in the construction of large sediment drifts that originate from the interaction of channelised turbidity currents traversing the continental rise, and along-slope bottom currents. These drift deposits are believed to contain a good and easily recoverable record of glacial history of the adjacent continental shelf, and have been the main target of a recently submitted ANTOSTRAT-ODP proposal.

3) *The East-Antarctic continental margin of the North-eastern Weddell Sea:*

Re-examination of high-resolution, analog seismic records in the vicinity of ODP Site 693 has allowed a number of fine-scale unconformities to be identified in addition to those defined previously. Three sub-sequences have been recognised within seismic units W6 and two in seismic unit W7. They all occur within the seemingly homogeneous Pliocene strata at ODP Site 693, consisting of clayey mud, diatom mud and silty and clayey diatom- bearing mud. They coincide with stratigraphic horizons characterised by spikes in smectite percentage in an overall illite-dominant lithology.

Smectite spikes probably indicate a change in sediment source from the Antarctic continent where glacial activity produced illite in response to direct rock erosion, to the continental shelf where previously hydrolysed Cretaceous and Tertiary sediments were exposed. Eroded detritus could have been transported to the shelf edge by ice sheets. Sediment-laden melt water debauching from the ice-sheet grounding line may have created low-angle erosional unconformities in the middle-slope deposits and may have initiated mass flow that moved downslope towards Wegener Canyon across the mid-slope bench. The smectite-horizons found at ODP Site 693 would represent overbank deposition. The unconformities and sequence boundaries identified on seismic sections on the slope off Cape Norvegia - outside the immediate influence of the glacial prograding wedge deposits - are therefore probably directly related to processes of ice-sheet expansion.

3 FIELD ACTIVITIES

Field activities i.e., at sea sampling and measurements, were achieved in the framework of scientific voyages to the Antarctic organized by other countries (see Table page 19).

Through their involvement in such campaigns, the research teams of the Programme were also provided with the unique opporunity to develop or strenghten international co-operation links. As an outcome, most of the Programme's research projects have been contributing to, and taking advantage of, the common implementation of internationally integrated studies.

Evidence of active international cooperation can by drawn from within the list of research papers presented under item 4 "Research Papers 1992-1997" (about 60% of all papers published over the last six years were authored jointly with at least one non-Belgian scientist).

FIELD ACTIVITIES

PERIOD	CAMPAIGN	SHIP, BASE	AREA	PROJECT	NAME (AFFILIATION)
Oct/93-Jan/94	ITALIANTARTIDE IX	Terra Nova Bay (Italy)	Terra Nova	Isotopic and chemical composition of Antarctic shelf ice (A3/11/002)	J.-L. Tison (ULB)
Dec/93	-	R/V Hesperides (Spain)	Bransfield Strait, de Gerlache Strait	Antarctic Offshore Acoustic Stratigraphy Project (A3/02/002)	Ph. Bart (RUG) M. De Batist (RUG) E. Van Heuverswyn (RUG)
Dec/94-Apr/94	-	Signy (United Kingdom)	Signy Island, South Orkney Island	Ecology of the meiobenthos (A3/02/001)	M. Beghyn (RUG) S. Vanhove (RUG)
Jan/94-Mar/94	ANTARKTIS XI/3	R/V Polarstern (Germany)	Amundsen Sea, Bellinghausen Sea	Antarctic Offshore Acoustic Stratigraphy Project (A3/02/002)	E. Maes (RUG) K. Vanneste (RUG)
Feb/94-Mar/94	ANTARES 2	M/V Marion Dufresne (France)	Indian sector of the Southern Ocean	Ecodynamics of the microbial planktonic food web (A3/11/001)	Ch. Lancelot (ULB) P. Menon (ULB)
				Transport of biogenic compounds (A3/03/001)	F. Dehairs (VUB) L. Goeyens (VUB) M. Semeneh (VUB)

PERIOD	CAMPAIGN	SHIP, BASE	AREA	PROJECT	NAME (AFFILIATION)
Oct/94-Jan/94	ROSSMIZE	R/V Italica (Italy)	Ross Sea	Dynamics of pelagic ecosystems (A3/12/001)	A. Goffart (ULg) J.-H. Hecq (ULg) C. Veeschkens (ULg)
Sep/95-Dec/95	ANTARES 3	M/V Marion Dufresne (France)	Indian sector of the Southern Ocean	Transport of biogenic compounds (A3/03/001)	M. Elskens (VUB) L. Goeyens (VUB)
				Ecodynamics of the microbial planktonic food web (A3/11/001)	P. Menon (ULB) J. Piraux (ULB)
Oct/95-Dec/95	ITALIANTARTIDE XI	Terra Nova (Italy)	Terra Nova Bay	Isotopic and chemical composition of Antarctic shelf ice (A3/11/002)	J.-L. Tison (ULB)
Dec/95-Feb/96	NZAP 95-96	(New Zealand)	Victoria Land		R. Lorrain (ULB)
Jan/96-Mar/96	CS-EASIZ	R/V Polarstern (Germany)	Weddell Sea	Ecology of the meiobenthos (A3/02/001)	M. Jong Lee (RUG) S. Vanhove (RUG)
Dec/96-Jan/97	GEBRA II	R/V Hesperides (Spain)	Bransfield Strait, Shetland Trench	Antarctic Offshore Acoustic Stratigraphy Project (A3/02/002)	M. De Batist (RUG) M. Van Cauwenberghe (RUG)

4 RESEARCH PAPERS 1992-1997

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6 ABBREVIATIONS AND ACRONYMS

ANTOSTRAT	Antarctic Offshore Acoustic Stratigraphy Project
ASTR	Institut d'Astronomie et de Géophysique G. Lemaître
ATCM	Antarctic Treaty Consultative Meeting
BAS	British Antarctic Survey
CS-EASIZ	Coast and Shelf - Ecology of the Antarctic Sea Ice Zone
BELANTOSTRAT	Belgian contribution to ANTOSTRAT
EPOS	European Polarstern Study
GEBRA	Evolución Geológica de la Cuenca de Bransfield y de la Dorsal Sur del Mar de Scotia
GPS	Global Positioning System
HPLC	High Performance Liquid Chromatography
MUMM	Management Unit of the Mathematical Model of the North Sea and Scheldt Estuary
NIPR	National Institute of Polar Research, Tokyo
NZAP	New Zealand Antarctic Programme
ODP	Ocean Drilling Program
OSMAS	Oil Spill Modelling for the Antarctic Seas
OSTC	Federal Office for Scientific, Technical and Cultural Affairs
PNRA	Programma Nazionale di Ricerche in Antartide
ROSSMIZE	Ross Sea Marginal Ice Zone Ecology
RUG	Universiteit Gent
SWAMCO	Seawater Microbial Community Model
UCL	Université Catholique de Louvain
ULB	Université Libre de Bruxelles
ULg	Université de Liège
VUB	Vrije Universiteit Brussel

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